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PHENOLOGY SATELLITE EXPERIMENT

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16. Abstract The detection of a phenological event (the Brown Wave-vegetation senescence) for specific forest and crop types using ERTS-1 imagery is described. Data handling techniques including computer analysis and photo-interpretation procedures are explained. Computer analysis of ERTS-1 multispectral scanner digital tapes in all bands was used to give the relative changes of spectral reflectance with time of forests and specified crops. These data were obtained for a number of the study's twenty-four sites located within four north-south corridors across the United States. Analysis of ground observation photography and ERTS-1 imagery for sites in the Appalachian Corridor and Mississippi Valley Corridor indicates that the recession of vegetation development can be detected very well. Tentative conclusions are that specific phenological events such as crop maturity or leaf fall can be mapped for specific sites and possibly for entire regions. Preliminary analysis based on a number of samples in mixed deciduous hardwood stands indicate that as senescence proceeds both the rate of change and differences in color among species can be detected. The results to date show the feasibility of the development and refinement of phenoclimatic models.

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Preface

The objective of the project is to develop techniques for identifying phenological changes and plant types on a broad scale. Phenological stages to be observed are the Green Wave and the Brown Wave (page 2).

A well-coordinated nationwide network of 24 ground observation sites (2.1) in four corridors has been established and ground photography documentation of phenological events has been continuous since the launch of ERTS-1.

Phenological data were recorded throughout the East and West during 1971 and 1972 on the phenological changes of selected indicator plants. These data are now being analyzed for indications of the fall progression of the Brown Wave.

Computer programs (2.2) were developed at Texas A & M University (Remote Sensing Center) and Purdue University (Laboratory for Applications of Remote Sensing) to process multispectral scanner measurements (MSS) of the Phenology Satellite Experiment test sites.

Work at the University of Maine and Cornell University has demonstrated that MSS imagery when analyzed with a Digicol Processor 4010-32 can reveal the spectral changes which occur during the Brown Wave (vegetation senescence).

A detailed data handling plan has been formulated for the routing of the test site data received from the NASA Data Processing Facility (NDPF). The plan is presently operational for ERTS-1 data handling (2.2.1) for the western and eastern United States.

During the spring and summer of 1973, work will be directed to the study of the second half of the objective, the Green Wave (3.0). Studies will also continue on the information obtained during the first six-month period.

Preliminary analysis (4.0) of digital data shows that a systematic decrease in reflectivity in the infrared channels occurred for the August to November period. This change reflects the progression of the Brown Wave with time at the different test sites.

Results to date from the Phenology Satellite Experiment shows the feasibility of the development and refinement of phenoclimatic models.

Satellite data, such as that received from ERTS-1, will make world-wide phenological monitoring possible. This is necessary to develop universally applicable phenoclimatic models.

For countries with highly developed agriculture, such information would be useful in characterization of crop status, yield prediction, and management planning. Phenological data in less-developed countries could be useful for agricultural land use planning and for determining site suitability.

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1.0 INTRODUCTION

This study is being conducted by the NE-69 and W-48 Regional Research Technical Committees[1] as an extension of their ongoing research in the development of methods for evaluation and utilization of remotely sensed data pertinent to agricultural ecosystems by ERTS and aircraft. The project involves research on the interpretation of remotely sensed data relevant to the Green Wave and Brown Wave (the seasonal and geographic procession of foliage development and senescence over wide areas) and their relationship to agricultural production.

The ERTS program is coordinated and directed by Dr. B. E. Dethier, Professor of Meteorology, Division of Atmospheric Sciences, Department of Agronomy, Cornell University, Ithaca, New York 14850. It uses the established facilities of 16 State Agricultural Experiment Stations, their substations and Phenological Network Stations and benefits from the experience gained through 16 years of closely coordinated regional and interregional research projects.

About one-half of the cost of the research in Agricultural Research programs has been funded by the cooperating states and about one-half by federal (USDA) regional research money distributed through State Agricultural Experiment Stations. The regional research is directed and coordinated by a technical committee which meets regularly.

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[1]In Addition to members of Regional Research Technical Committee NE-69, the research team includes members of the former Regional Research Technical Committee W-48.

Regional Research projects such as NE-69, Atmospheric Influences on Ecosystems and Satellite Sensing, and W-48, Climate and Phenological Patterns for Agriculture in the Western Region, are funded jointly by participating State Agricultural Experiment Stations and by federal regional research money from Cooperative State Research Service, USDA.

The objective of this project is to develop techniques for identifying phenological changes and plant types on a broad scale. Phenological stages to be observed are as follows:

(a) The Green Wave: A record of the geographical progression with time of foliage development over wide areas is the first step that must be taken toward a real time inventory of the yield potential, yield realization and crop management over extended crop and timber producing areas of the nation.

(b) The Brown Wave: A record of the geographical progression with time of vegetation senescence (maturation of crops, leaf coloration, and leaf abscission) plays the analogous role in the autumn as the Green Wave phenomenon does in the spring in terms of phenological predictors for vegetation management.

Due to the launch date of ERTS-1, this report concentrates on the ground observation initiated and results to date on the study of the Brown Wave and some of its applications and uses for Agriculture and Forestry.

1.1 BACKGROUND

Phenology is the science concerned with periodic biological events in their relation to seasonal climatic changes and is known as the science of appearances because emphasis is placed on dates of various occurrences. The term "phenology" appears to have been first applied in 1853 by the Belgian botanist, Charles Morren, to that branch of science which studies the periodic phenomena in the plant and animal world insofar as they depend upon the climate of any locality. The word phenology itself is derived from the Greek word "phaino", meaning to show. Plants can be used as indicators of climatic differences because the times of occurrence of phenological events of many plants is to a large degree controlled by the weather. Thus, phenology represents a merging of the meteorological and biological sciences, each contributing something to the other.

Phenological records for agricultural crops have been kept for many years at the agricultural experiment stations throughout the country. These data are valuable to the agricultural scientist because they provide a basis for comparing relative earliness or lateness of developmental stages for different crop varieties, since effects of weather on crops are highly dependent upon concomitant stages of plant development. Such comparisons are often used as a basis for selecting those particular varieties that are most adapted for specific locations. However, once a crop variety has been proven most adaptable for the places where it has been tested, it is not always possible to specify where it will grow most successfully because too little is known about the nature of climate and the developmental behavior of plants in areas away from the experimental sites. This gap of information can be narrowed by the use of phenological indicator plants which reflect climatic contrasts between locations through their differential rate of seasonal development.

The observation of phenological events at numerous locations, resembling in some respects national climatological networks, provides useful information for many aspects of human activity, but is particularly important for application in agriculture.

Localized phenological observations have been made in the United States from time to time and usually were terminated after a number of years. However, phenological networks started in Montana in the mid 1950's provided the impetus for the establishment of new phenological networks and the expansion of existing networks in the western, north-central and northeastern regions using clonally propagated plant material. The phenology networks (Fig. 1) now cover 40 states and 5 Canadian Provinces and include

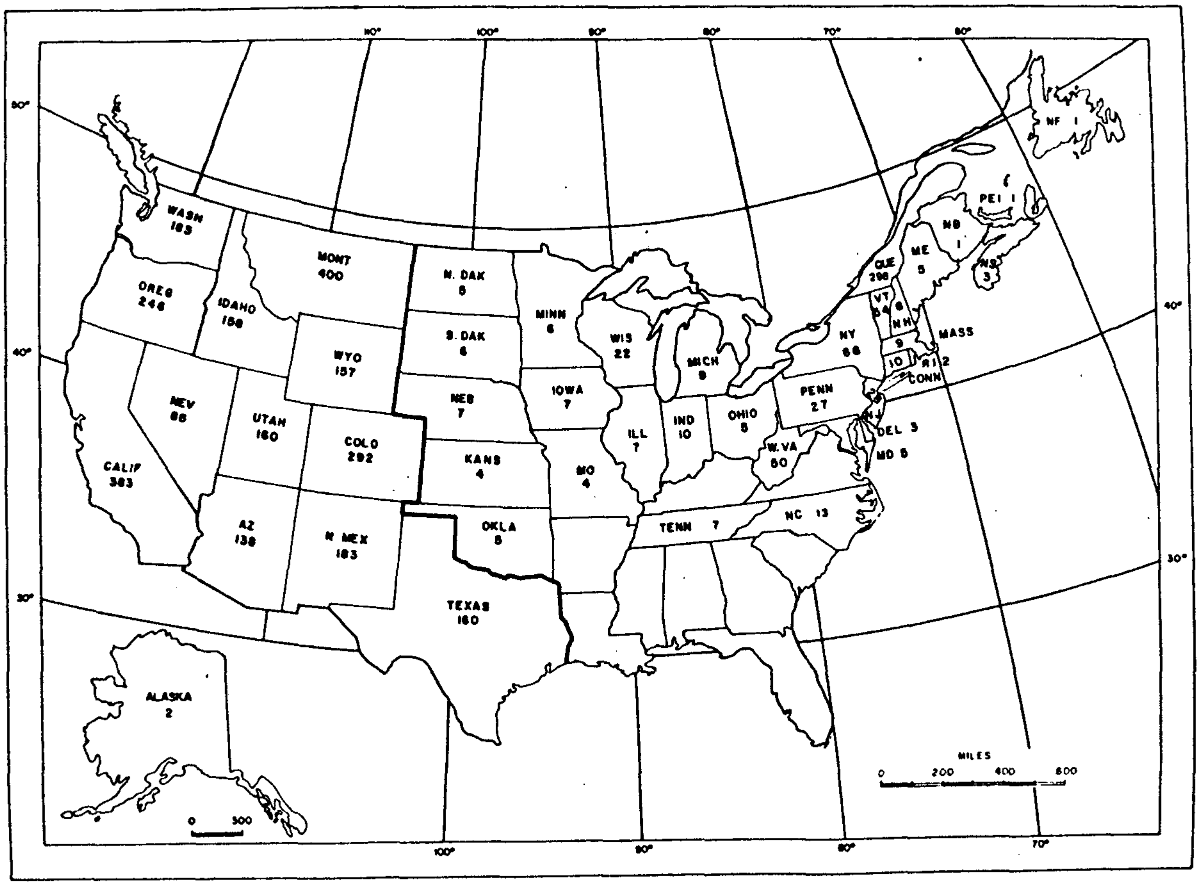


Figure 1. Phenology Networks. Numbers indicate total observation sites in each state or province.

over 3200 sites. Standardized instructions (1,2) were developed to insure uniformity in gathering of the data. Most observation sites are located near weather stations to allow for comparisons between phenological data and meteorological parameters.

2.0 ACCOMPLISHMENTS

The diverse components of the ERTS-1 project necessitated close cooperation and coordination. To achieve the meaningful merging of research products, the following organization structure, as shown on page 6, was successfully implemented.

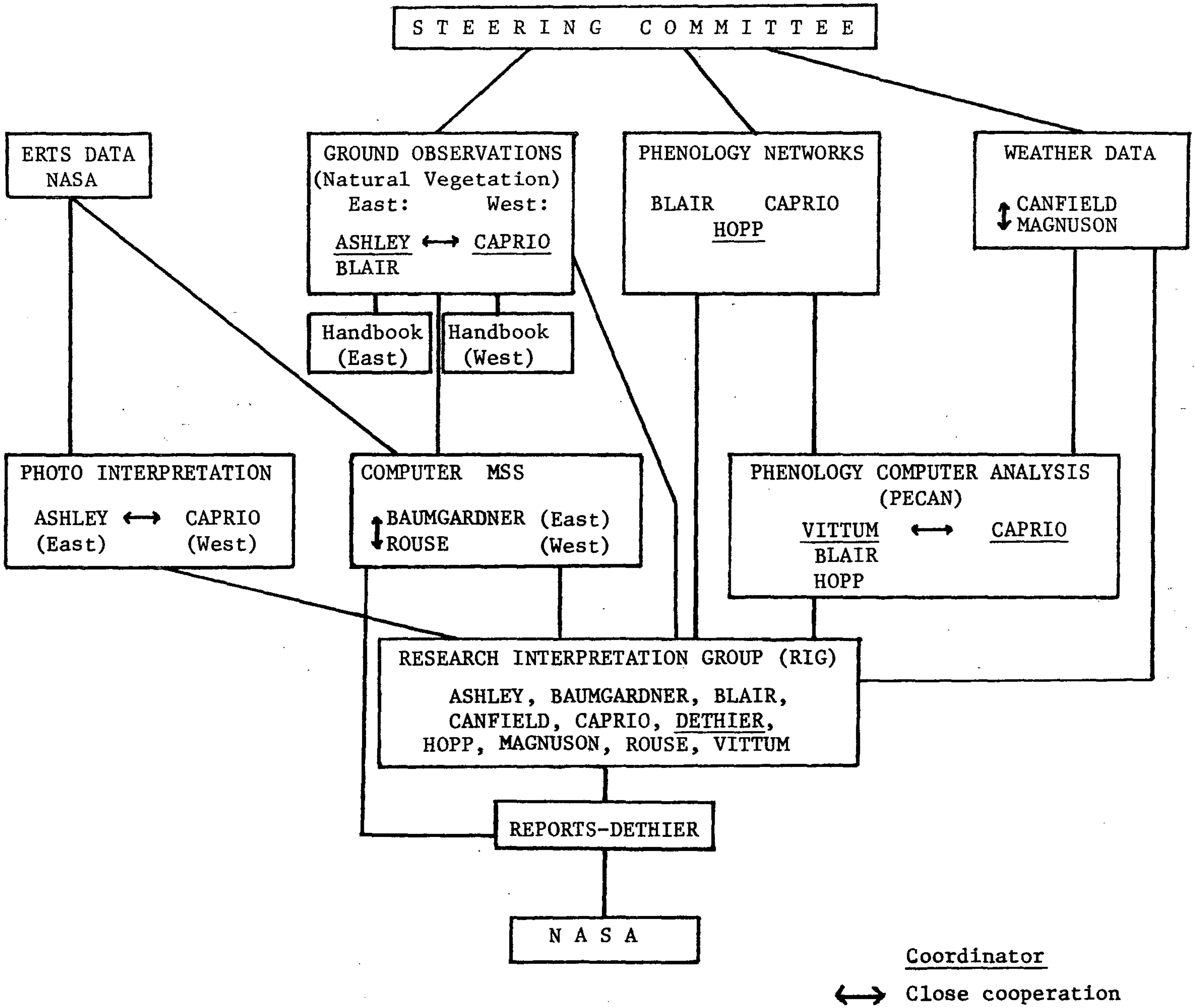
2.1 GROUND OBSERVATIONS

A well-coordinated nationwide network of 24 ground observation sites (Fig. 2) in four corridors has been established and ground photography documentation of phenological events has been continuous since the launch of ERTS-1.

Field procedures were established to obtain ground photography of the same scene on different dates. Manuals (3,4) which describe these field procedures in detail were distributed to the observers.

The advance of the Brown Wave (leaf coloration and leaf fall) with time at the Orono, Maine, site is illustrated in Fig. 3 and similar documentation of the maturation of certain agricultural crops (corn, wheat, tobacco, cotton, alfalfa, soybean, sorghum, grapes and apples) has also been obtained at some of the other sites.

An example of the Green Wave (record of plant development with time) is shown in Figure 4. These photographs were taken in the spring and summer of 1972 at Burlington, Vermont. These are two examples of the data


S T E E R I N G   C O M M I T T E E
ERTS DATA NASA
GROUND OBSERVATIONS (Natural Vegetation)
East: West:
ASHLEY CAPRIO
BLAIR
Handbook (East)
Handbook (West)
PHENOLOGY NETWORKS
BLAIR CAPRIO
HOPP
WEATHER DATA
CANFIELD
MAGNUSON
PHOTO INTERPRETATION
ASHLEY (East) CAPRIO (West)
COMPUTER MSS
BAUMGARDNER (East)
ROUSE (West)
PHENOLOGY COMPUTER ANALYSIS (PECAN)
VITTUM CAPRIO
BLAIR
HOPP
RESEARCH INTERPRETATION GROUP (RIG)
ASHLEY, BAUMGARDNER, BLAIR, CANFIELD, CAPRIO, DETHIER, HOPP, MAGNUSON, ROUSE, VITTUM
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N A S A
Coordinator
Close cooperation

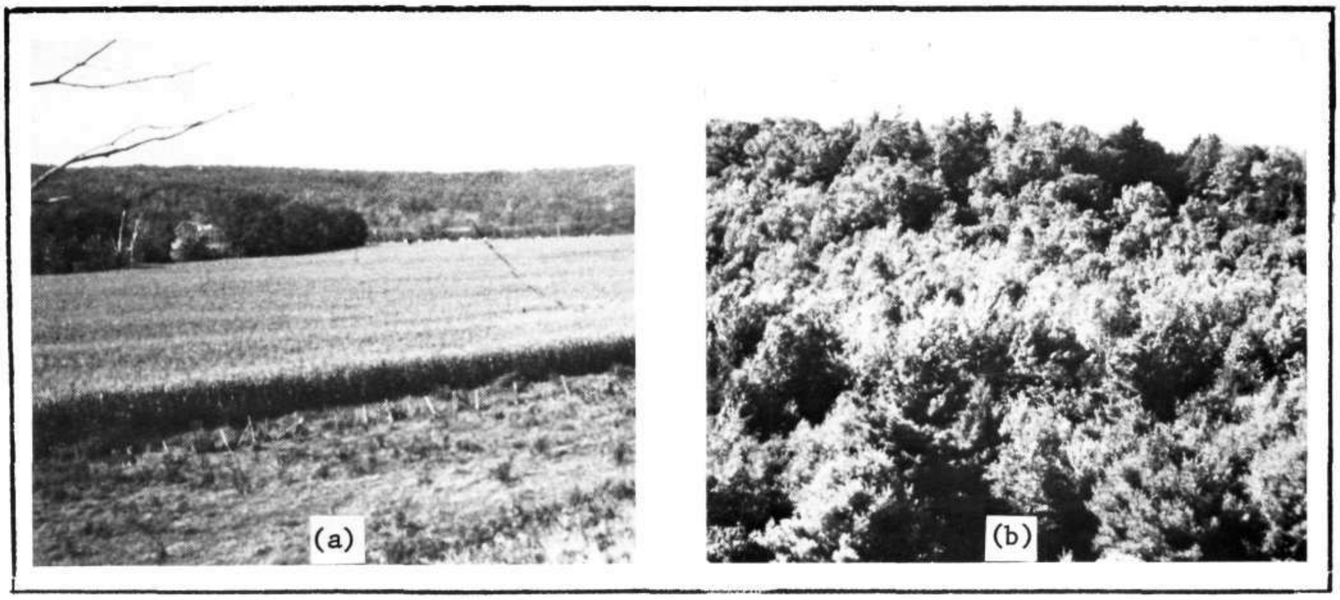

Figure 2a. Typical Appalachian Corridor (Vermont) ground observation sites: a) field crop and b) forest.

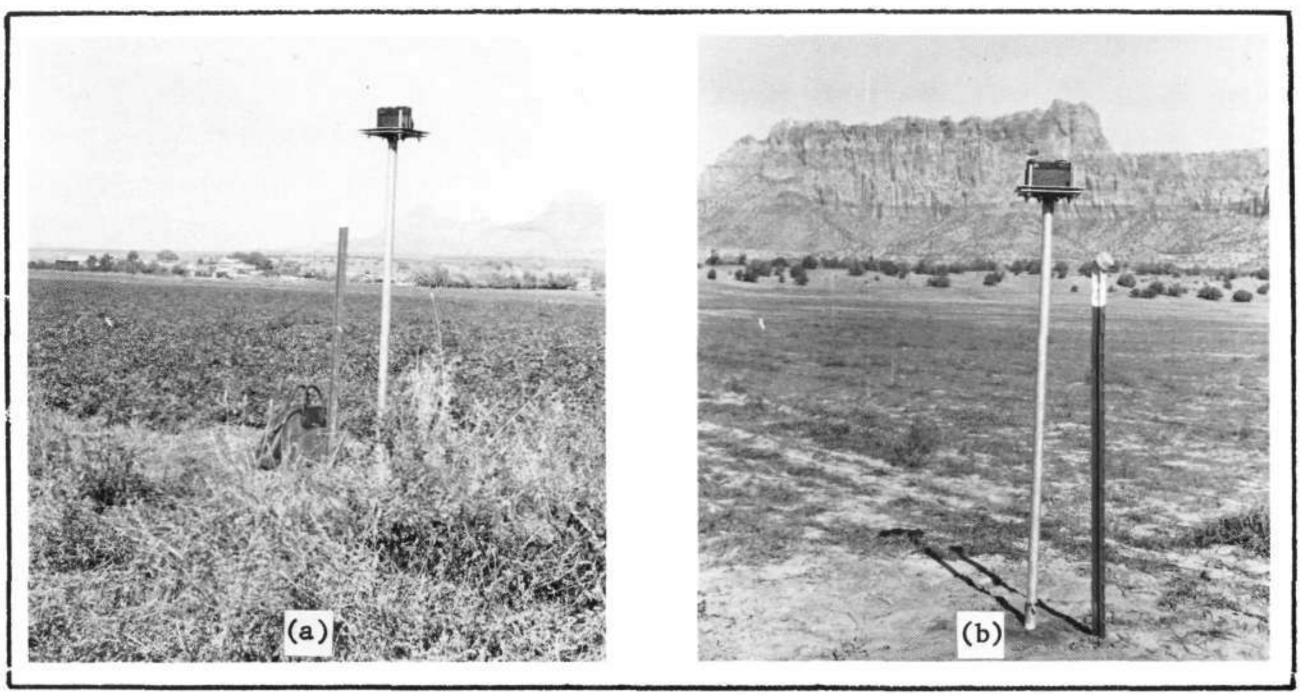

Figure 2b. Typical Rocky Mountain Corridor (Montana) ground observation sites: a) irrigated crop and b) prairie.

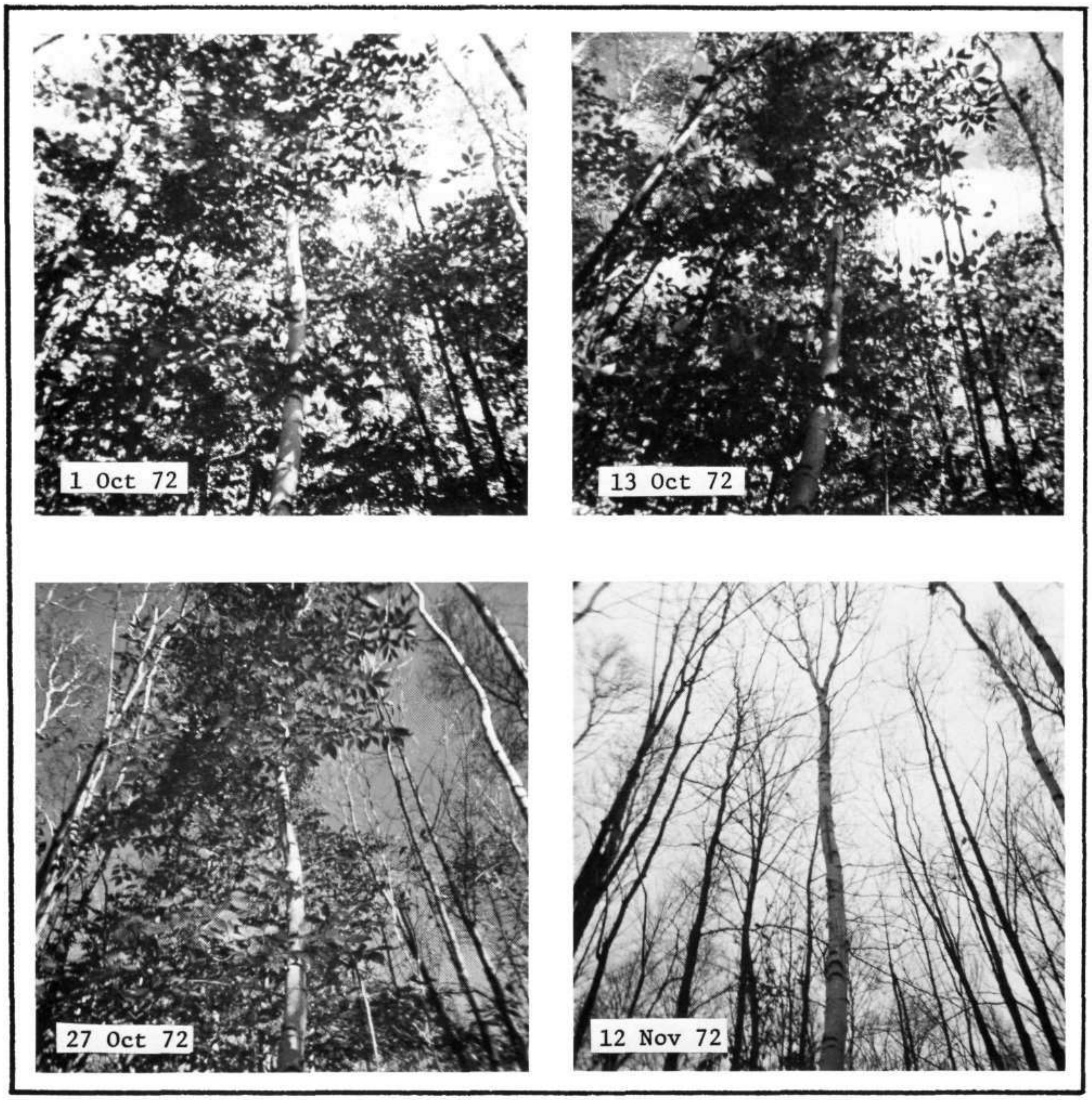

Figure 3. Brown Wave (leaf coloration and leaf fall with time) at Orono, Maine, 1972.

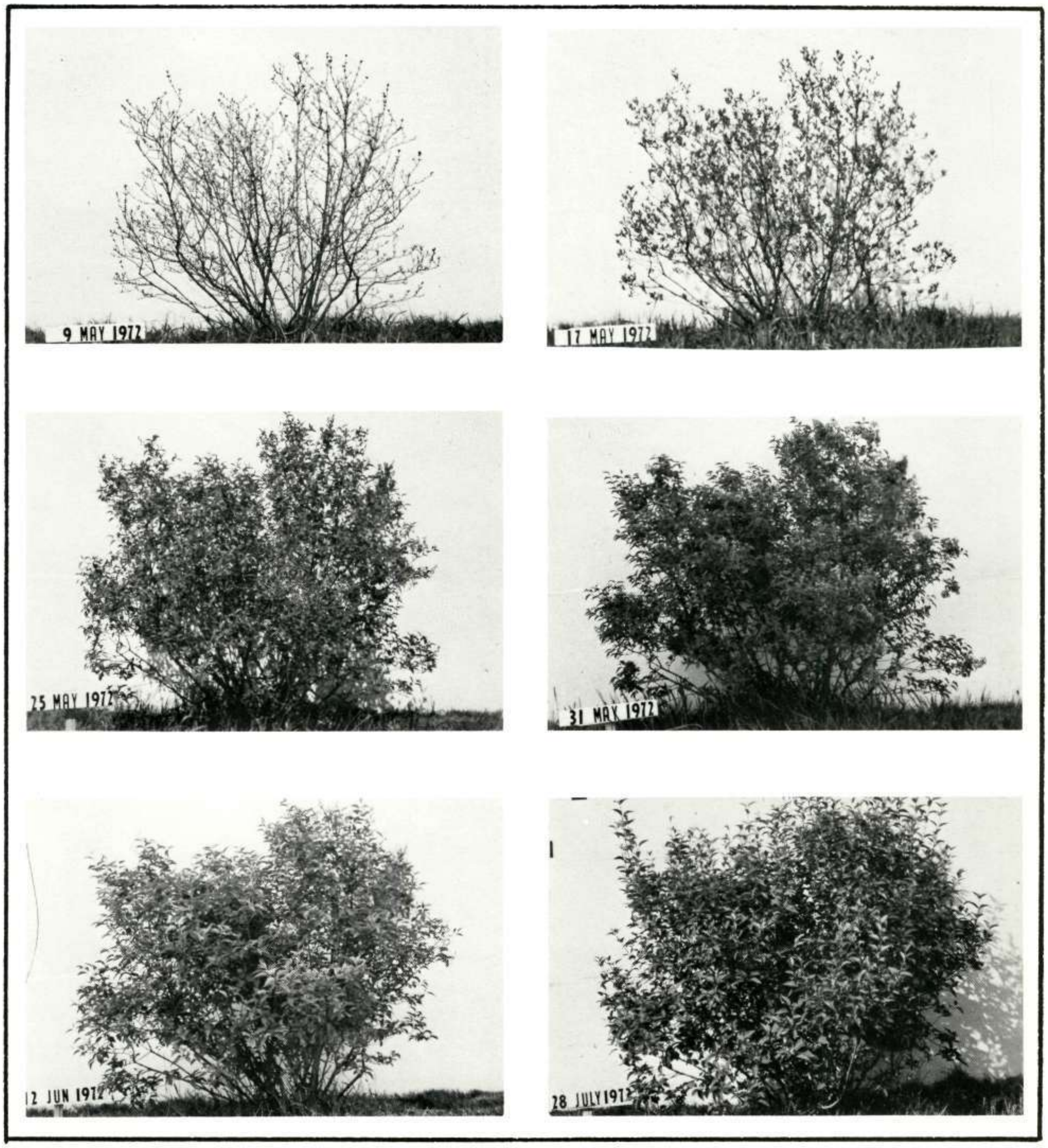

Figure 4. Green Wave (lilac development with time) at Burlington, Vermont, 1972.

collected from phenological networks and corridor sites established under the Phenology Satellite Project.

The data from these networks are being used to construct maps showing the dates of occurrence by certain phenological events over the U.S. (Fig. 5) and the northern hemisphere (Fig. 6).

Weather data were collected from existing National Oceanic and Atmospheric Administration (NOAA) stations representative of the prime ground observation sites. The parameters being used in the phenology-weather data analysis include:

Crop moisture index (Palmer). Available currently with 1-week time lag. This index is not localized but representative for areas. Available from March through November.

Growing Degree Days. GDD accumulations available starting March 1, of daily air temperature departures from base 10°C with lower and upper limit modifications, primarily designed for corn. This may not be suitable for plants such as grass and forest trees. A 0°C base temperature for GDD with a 30°C upper limit adjustment appears preferable for this study.

Solar Thermal Units (Radiation-adjusted GDD) proposed by Caprio (Montana Agr. Exp. Sta. Circ. 251, 1971).

Other parameters available from daily weather data tapes.

2.1.1 Appalachian Corridor (Fig. 7)

This corridor extends from Bangor, Maine, westward to Burlington, Vermont, southwest to Morgantown, West Virginia, then south to Raleigh, North Carolina. Most of the corridor is through the Hill Country Habitat where topography is characterized by maturely dissected plains, low plateaus, foothills and old worn-down mountains. The northern one-third

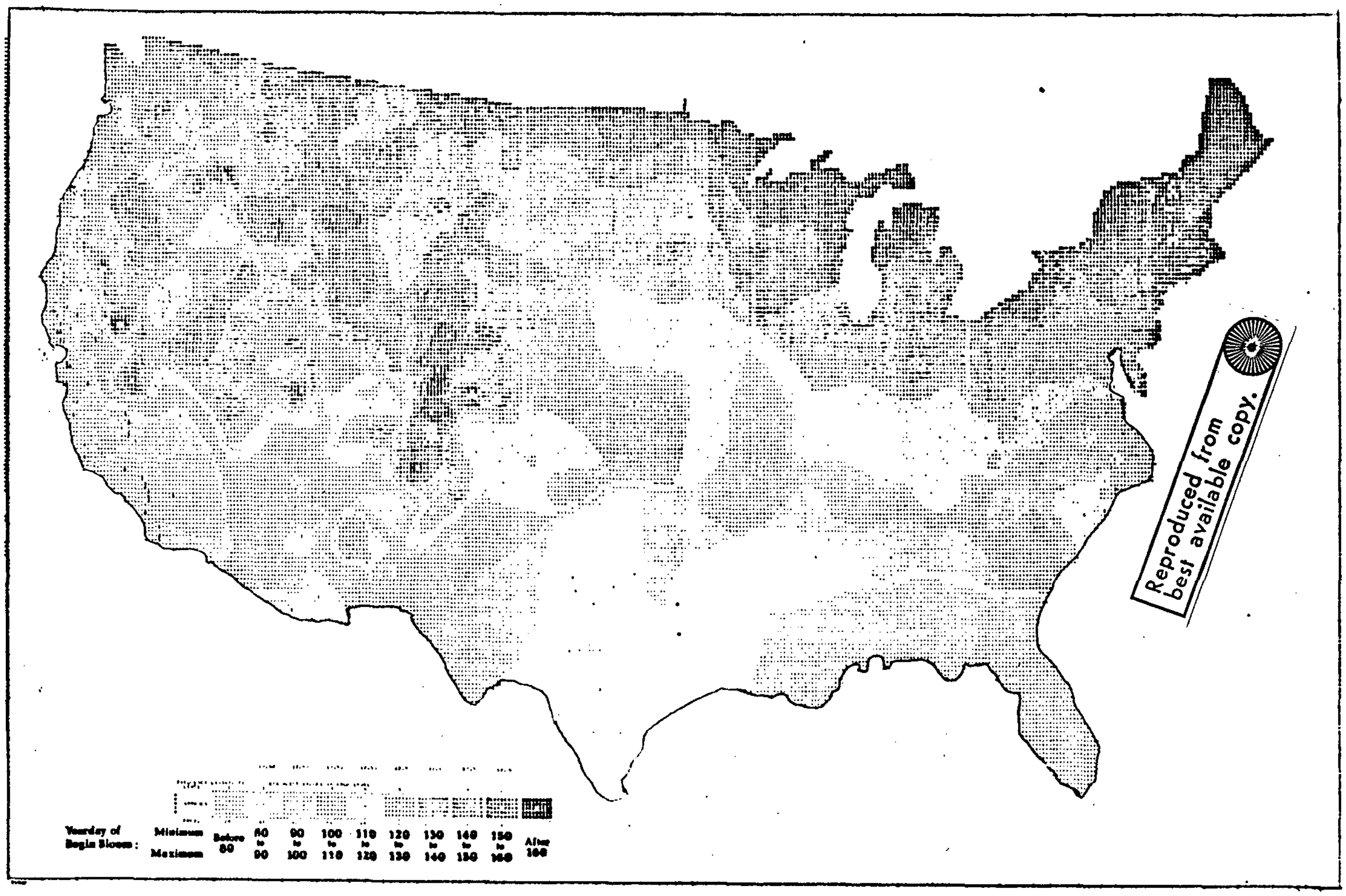

Figure 5. Onset of Spring 1971 as indicated by bloom dates of several plant species.

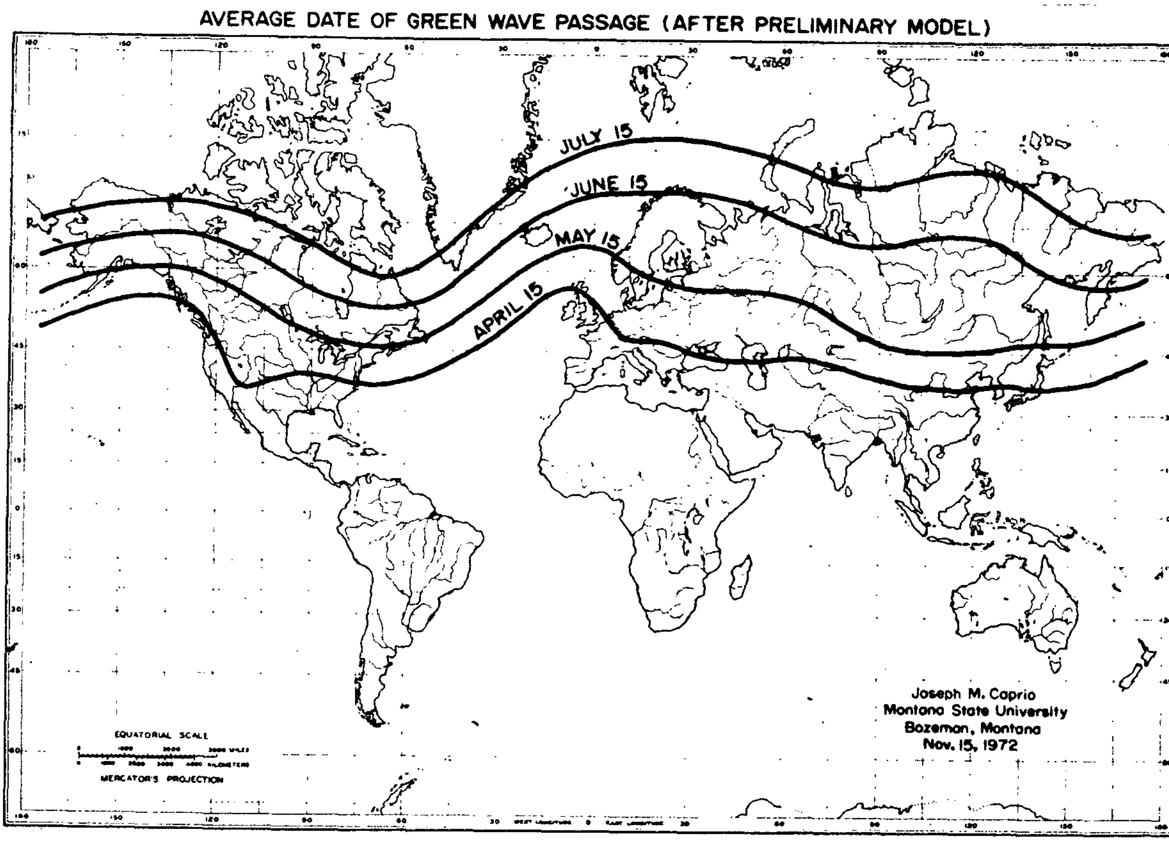

Figure 6. Average date of Green Wave Passage.

of the corridor has a humid microthermal climate while the remainder has a humid mesothermal climate.

The natural vegetation is shown in Figure 7. Seasonal changes in the spectral signatures of northern hardwoods and oak forests will be observed and related to ground observations from the phenological networks.

Dairying and livestock rearing are important to this region, as are field crops (hay, alfalfa, corn, etc.), vegetable and fruit crops, and certain high value crops, i.e. grapes. Forest industries contribute greatly to economy through the production of newsprint, naval stores, and the harvesting of timber.

2.1.2 Mississippi Valley Corridor (Fig. 7)

This corridor extends from Lansing, Michigan, south to central Indiana, southwest to eastern Oklahoma, then south to College Station Texas. Most of the corridor is classified as Plains Habitat of the interior, alluvial, and glacial types. Like the Appalachian, the climate ranges from a humid mesothermal in the south to humid microthermal in the north.

The natural vegetation is shown in Figure 7. Seasonal changes in the spectral signatures of oak forests will be observed and related to ground observations from the phenological networks.

Mixed agriculture predominates in this region with emphasis on corn. cereal grains, and livestock production.

2.1.3 Rocky Mountain Corridor (Fig. 7)

This corridor extends from northern Montana due south to northern Arizona. The region is classified primarily as a combination of Mountain Habitat and Plateau Habitat of the intermontane basin and tableland variety with a few lacustrine plains.

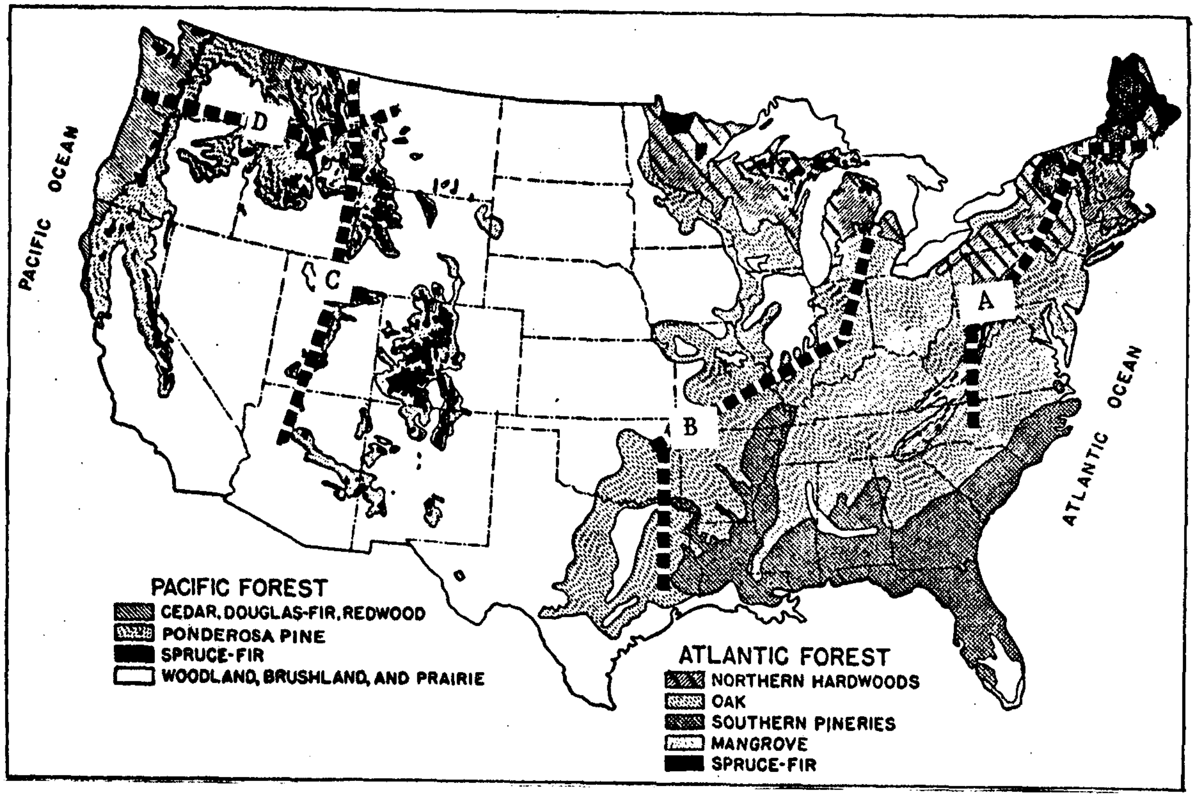

Figure 7. A - Appalachian Corridor, B - Mississippi Valley Corridor, C - Rocky Mountain Corridor, D - Columbia Valley Corridor.

The climates of this corridor are very diverse. The northern section has a humid microthermal climate which changes to a mesothermal, warm, dry summer climate in parts of Utah, then back to a humid microthermal and eventually becomes a middle latitude steppe climate in Arizona.

The natural vegetation is shown in Figure 7. Seasonal changes in the spectral signatures for prairie grasslands from sites of equal elevation (1450 m) will be observed and related to ground observations from the phenological networks.

Livestock production is the main agricultural enterprise in this corridor and farming is primarily devoted to the support of this industry.

2.1.4 Columbia Valley Corridor (Fig. 7)

This corridor extends from north central Montana due westward to south central Washington. It is classified a combination of Mountain Habitat and Plateau Habitat. The corridor has a microthermal, warm summer climate.

The natural vegetation is shown in Figure 7. Seasonal changes in the spectral signatures for prairie grasslands from sites of equal elevation will be observed and related to ground observations from the phenological networks.

Livestock and grain production are the major agricultural activities in eastern and western sections of this corridor with some forest industries in the central section.

2.1.5 Phenological Data

Information was recorded throughout the East and West during 1971 and 1972 on the phenological changes of selected indicator plants (5,6).

These data are now being analyzed for indications of the fall progression of the Brown Wave.

Report forms were prepared and mailed for the collection of phenological information pertinent to the Phenology Satellite Experiment for the 1973 growing season. Mailings to more than 2,500 observers are staggered from January to May, depending upon the normal pattern of phenological development throughout the country. Phenological data collected in 1972 are being prepared for computer analysis.

2.1.6 Solar Thermal Units

Solar Thermal Units (7) have been calculated by computer for locations in the world where both long-term solar radiation and temperature records are available. Average daily and accumulated values of STU for each day of the year have been determined for each station. From this information rough estimates of world-wide average patterns of phenological events are being constructed. World maps have already been drawn for the Green Wave (Fig. 6, page 12).

2.2 DATA HANDLING

Computer programs were developed at Texas A & M University (Remote Sensing Center) and Purdue University (Laboratory for Applications of Remote Sensing) to process multispectral scanner measurements (MSS) of the Phenology Satellite Experiment test sites.

Work at the University of Maine and Cornell University has demonstrated that MSS imagery when analyzed with a Digicol Processor 4010-32 can reveal the spectral changes which occur during the Brown Wave (vegetation senescence).

2.2.1 PROCESSING

The objective of this activity is to prepare the ERTS-1 MSS data in a form facilitating analysis by the phenology network monitors. This required the development of a standard data product format and implementation of a data processing system insuring orderly data flow and reduction consistant with the product specifications.

A detailed data handling plan has been formulated for the routing of the test site data received from the NASA Data Processing Facility (NDPF). The plan is presently operational for ERTS-1 data handling and is graphically presented in Figure 8 for the Western Corridors. Figure 9 presents the data analysis procedure for the Eastern Corridors. Standing product orders are included for image products of the principal test sites. Upon receipt of imagery the data are cataloged and an individual file is prepared for the data from each test site. Evaluation of the imagery quality with respect to cloud cover, image noise, and site locatability is also performed. For those satellite passes where evaluation of the imagery is favorable, digital image products are routinely ordered.

Digital data tapes are cataloged upon receipt and site processing is performed. A site processing report is generated and the computer data catalog is updated.

Continuing data analyses is provided for statistical correlation and regression analysis of data. Statistical significance testing is also performed, as well as other analyses relating to information content.

Several stages of data processing are necessary for the analysis of the ERTS data. A site processing procedure is utilized for the immediate analysis of data received from the established phenological network test sites. Periodic processing is performed to relate these data to the

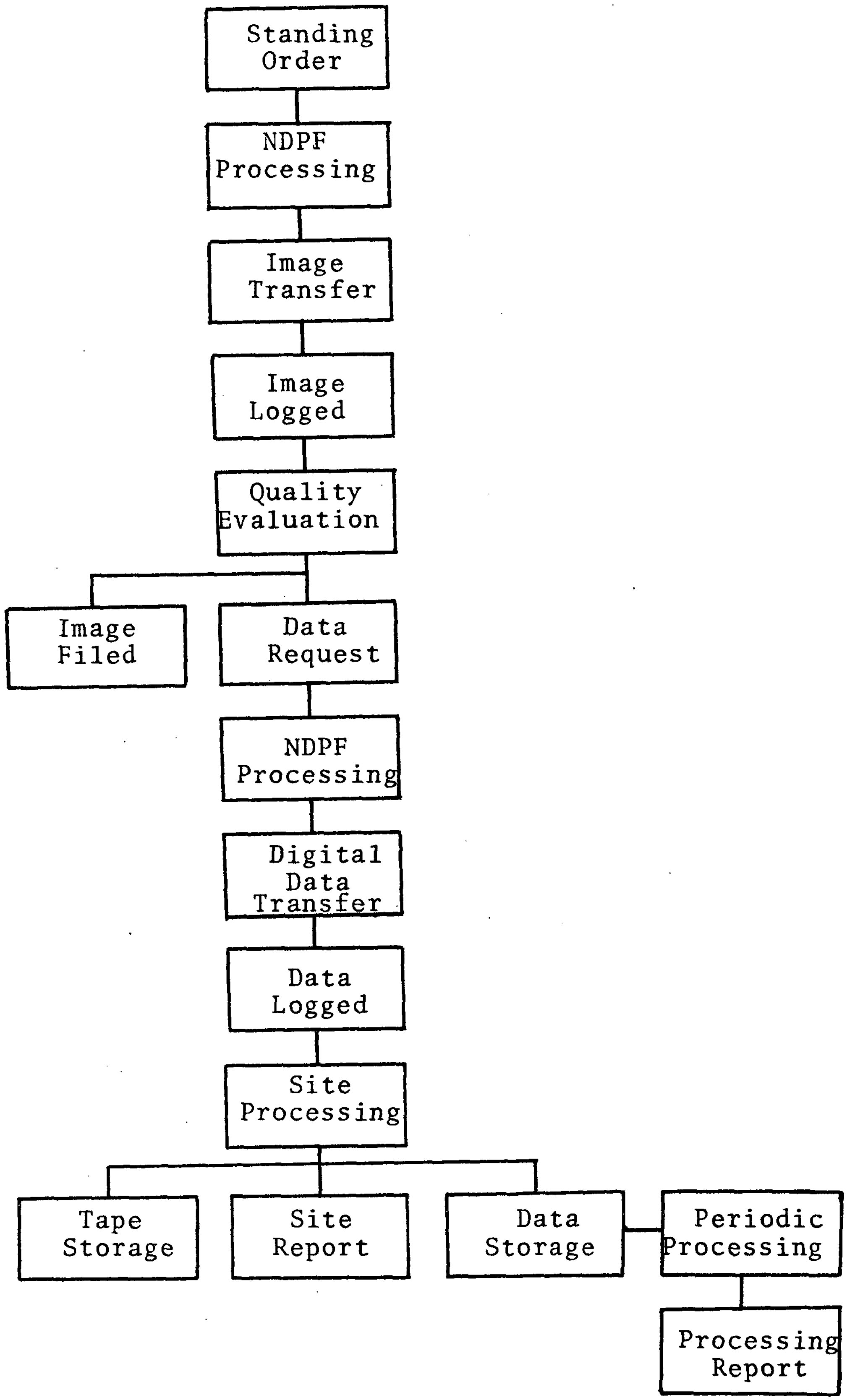

Figure 8. ERTS data handling plan for the Western Corridors.

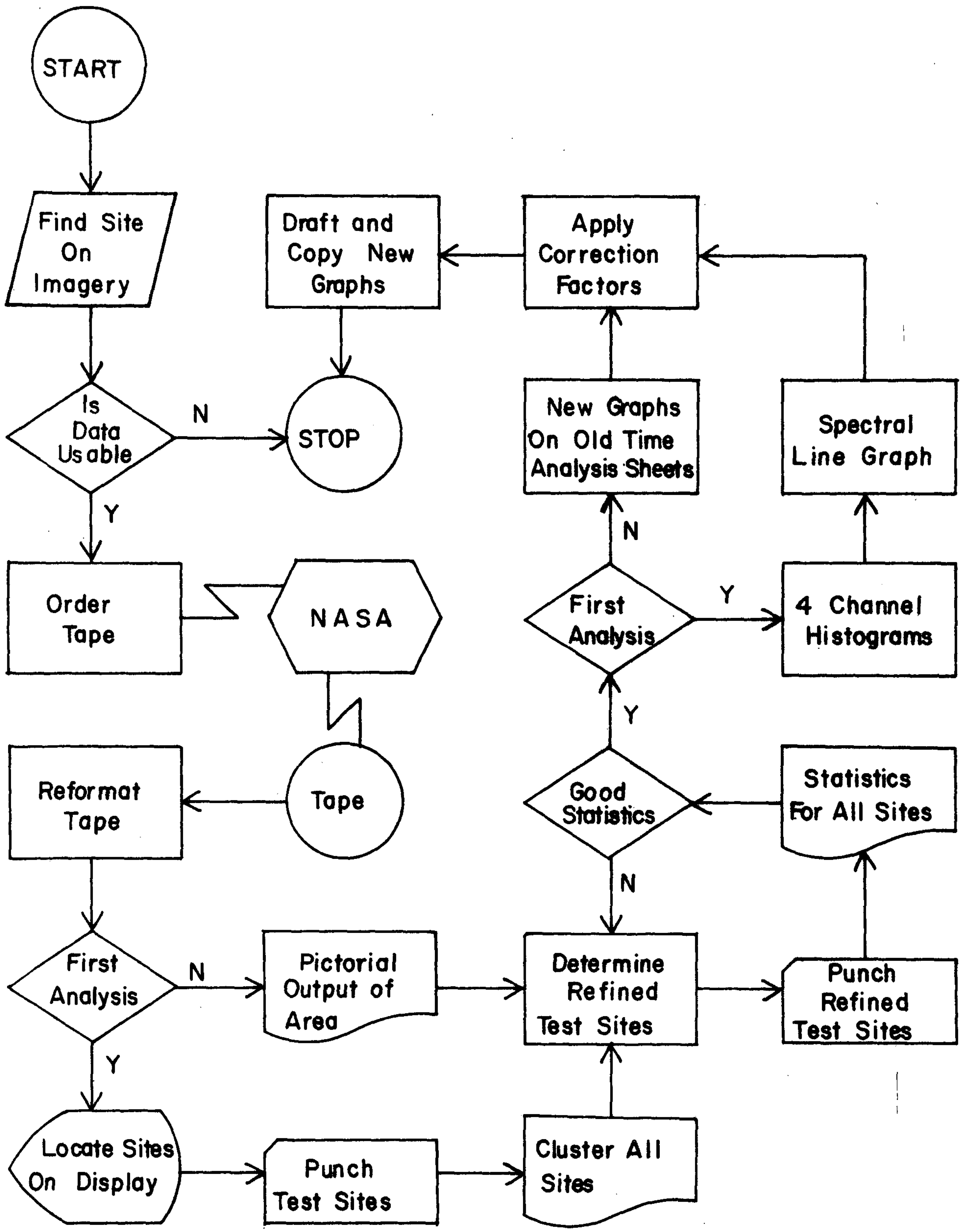

Figure 9. Data analysis procedure for the Eastern Corridors.

satellite measurements over time and space. Special data processing is performed on an opportunistic basis to increase the general body of knowledge relating to ERTS data utility and application area.

When digital data on the Western Corridors are received from NDPF, site processing is performed to locate the site exactly in the tape records and to extract and summarize the information available from the MSS measurements of the site.

The data processing is accomplished in several steps. The first of these steps is directed at locating the test site within the data tapes. Orbital parameter control of the satellite does not allow the site to be referenced directly by latitude and longitude with sufficient precision for processing. In order to precisely locate the test site, interactive manual interpretation is required. To accomplish this interpretation and still maintain the efficiency of the data system, data from an 18.5 km square, centered on the tape reference, computed from the orbital parameters and the site coordinates, is extracted from the digital tapes. These data are stored in high speed magnetic disc files for future reference, together with the header information from the tapes.

Illustrated in Figure 10 is the gray-scale density printout display of selected MSS bands on a computer line printer for manual interpretation. Using this technique, radiance intensity levels are related to printer letters which have been chosen specifically for their differing ink densities. Printing lines of the density selected letters corresponding to image element intensities along a scan presents an image representation which is directly related to the tape records. Key landmarks in the proximity of the site can be observed from this gray-scale map and their exact tape coordinates related to their terrain corrdinates. This information is provided to the next step of processing which can then exactly locate the

Figure 10. Columbia Valley test site image, Bickleton, Washington (1040-18204).

test site with reference to the landmarks. This processing step is implemented on an IBM 360/65 digital computer.

In the second step of site processing, the tape and terrain coordinates determined from the interpretation of the displayed data are used to determine the tape coordinates of the test site to be processed. The landmark references are also cataloged with the data set for future reference. The data is read from the high speed disc and the site data extracted according to the previously determined tape coordinates. The data from specified subsite areas are processed and the subsite spectral signature means and covariances are determined. This information is utilized to calculate the phenological indicator parameter for each subsite and this is inserted into the computerized site data catalog. Additionally, this information is made available in the form of a computer-provided site processing summary report.

A site processing summary report, as illustrated in Figure 11, is generated as a result of processing one overpass of a test site. Included in the site report is a description of the data source as obtained from the digital tape header. This includes observation identifier information, ERTS frames' center coordinates, NDPF processing parameters, orbital parameters, and time information. A brief description of the processed site is provided, as well as subsite sections at the option of the data requestor. Processed data tabulations are a part of the report which includes spectral signature means and covariances in physical units for each of the subsites, as well as calculated phenological indicator parameters. Subsite spectral signature means and variances are also presented graphically for evaluation.

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GREAT PLAINS CORRIDOR

    SITE    GP 1          0.6 BY   0.8 MILES

CENTER AT   30 DEGREES   39 MINUTES NORTH LATITUDE
            96 DEGREES   23 MINUTES WEST LONGITUDE
IMAGE NUMBER 1092-16305
ERTS-1, 092 DAYS SINCE LAUNCH
TIME(GMT) 16 HOURS 30 MINUTES 50 SECONDS
TAPE 3 OF  4 TAPES
DATA RECORD LENGTH   3296
ANNOTATION TAPE NUMBER SI113709
NDPF CODE 00100111
ADJUSTED SCAN LINE LENGTH 3240
THE HEADING OF THE SATELLITE (INCLUDING YAW) IS 189 DEGREES.

FRAME CENTER 30 DEGREES 13 MINUTES N LATITUDE
             96 DEGREES 45 MINUTES W LONGITUDE
LINE  525 IS THE FIRST LINE CONTAINING DATA FROM THE SITE.
CELL  519 OF TAPE 3 IS ON THE WEST EDGE OF THE SITE.
THE WIDTH OF THE SITE IS   16 CELLS.
THE SITE EXTENDS FOR   16 SCAN LINES.

THE SITE CONTAINS    256 CELLS.
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RADIANCE(MWATTS/SQCM-STR-MICROMETER)

	MEAN	STANDARD DEVIATION	WAVELENGTH (MICROMETERS)
BAND 1	4.76	0.36	.5 - .6
BAND 2	3.06	0.47	.6 - .7
BAND 3	4.07	0.29	.7 - .8
BAND 4	4.00	0.26	.8 -1.1

NORMALIZED COVARIANCES

	BAND 1	BAND 2	BAND 3	BAND 4
BAND 1	1.000	0.773	0.594	0.518
BAND 2	0.773	1.000	0.683	0.531
BAND 3	0.594	0.683	1.000	0.657
BAND 4	0.518	0.531	0.657	1.000

Figure 11. Example of site processing summary report.

A slightly different method of processing is used for the Eastern Corridors because the sites are small in area.

When the tapes arrive, the area of interest is reformatted and, if this is the first analysis of the site, the approximate area of the test site is located. In the analysis of Lafayette, Indiana, data it was found useful to supplement the original forested sites with additional forested sites which were chosen by a process referred to as computer "mapping". When it was found that certain sites were not represented by enough useable data points to allow a valid statistical analysis through computer algorithms, the limits of the spectral response for the useable sites were obtained. A simple gray-scale printout in channel 2 which would delineate only the areas within the response limits obtained from the original test sites was generated. Channel 2 was used for the printout because it was evident from previous digital display work that forested areas corresponding to those shown on USGS topographic maps were most prominent in this electromagnetic band.

As a final check on the validity of the mapping procedure, the output was hung on a wall and an aerial photographic negative of the same area was projected onto the gray-scale printout. When major features such as highways and streams coincided, it was possible to check the accuracy of the printout against the information obtained from the negative. There was an almost perfect correlation between forested areas on the gray-scale and forested areas on the negative. The only discrepancies occurred in small wooded areas of an acre or so which could not be accurately detected on the printout.

This process was also applied to the Lansing, Michigan, data where only two useable overpass dates were available and the original test site was covered by clouds on one of these. A computer printout of the wooded areas to the west of Lansing was obtained for the good data and the corresponding sites were then found for the partly cloudy data. Thus, the mapping procedure has given a temporal comparison for the Lansing area which would otherwise have been impossible.

A clustering program using data from two of the four channels is used to locate the most homogeneous area within the test sites for analysis.

If the particular test site has been previously analyzed, a pictoral printout of the general area is obtained using either channel two or four, depending on what identifying features are to be emphasized. The test sites used in previous analysis are then located on the printout. After test sites have been found, field boundaries are punched and used in the statistics programs to obtain individual site and class histograms, means and standard deviations.

These results are checked for any statistically poor sites and any individual site deviations from the class norm. If necessary, the fields are redefined and all new statistics are obtained.

Temporal comparisons, to date, have dealt mainly with forest canopies. Histograms have been obtained showing the relative spectral response in all four channels for each of the test sites for which time lapse data is available. These temporal responses have been plotted on a single graph for each test site in each channel and are shown in Figures 12-16. Figures 17 and 18 show the average response in each channel for all dates for a given test site. This information is shown for all but the New York and Texas data.

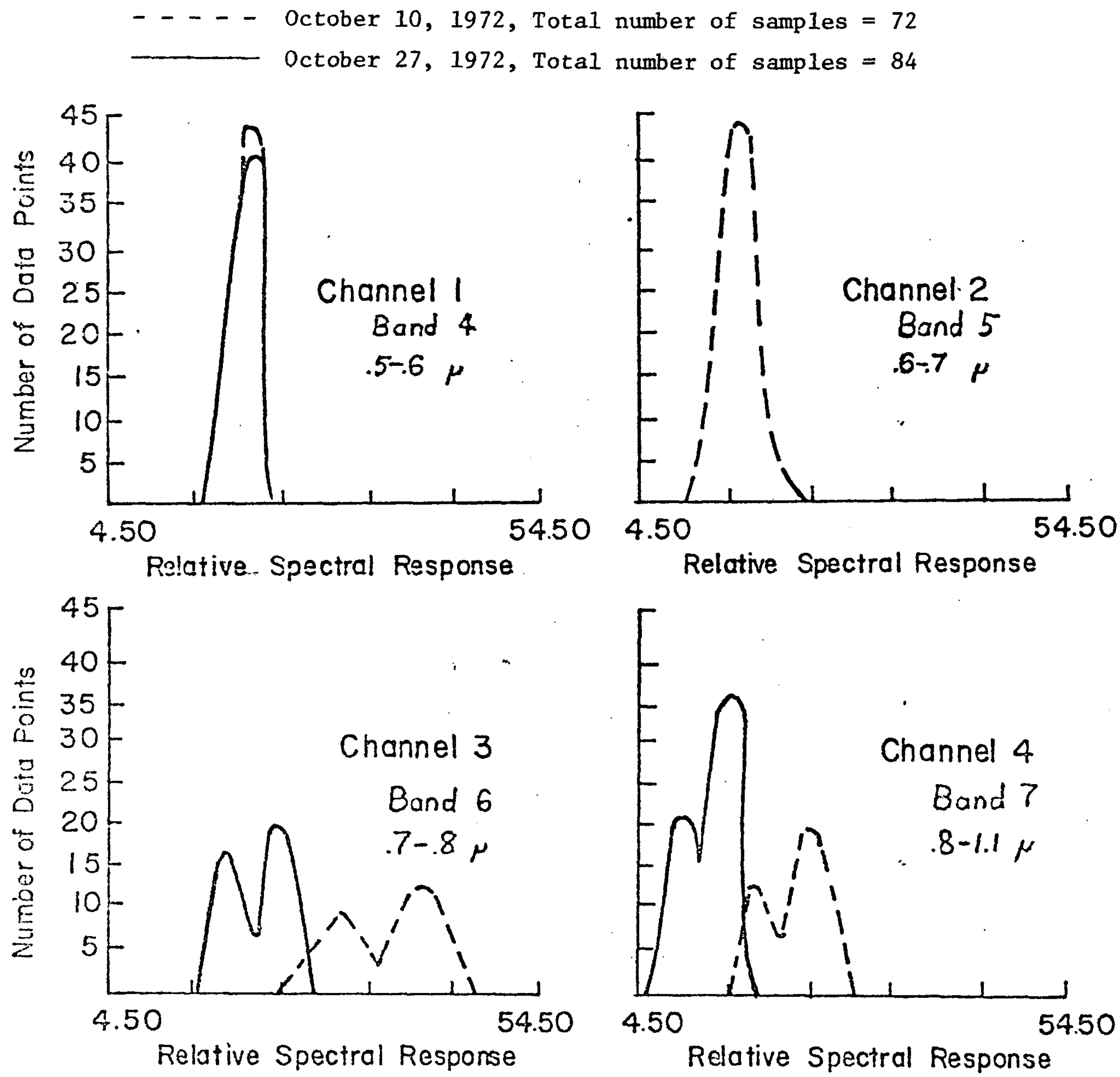

Figure 12. Time lapse analysis of Vermont forested sites.

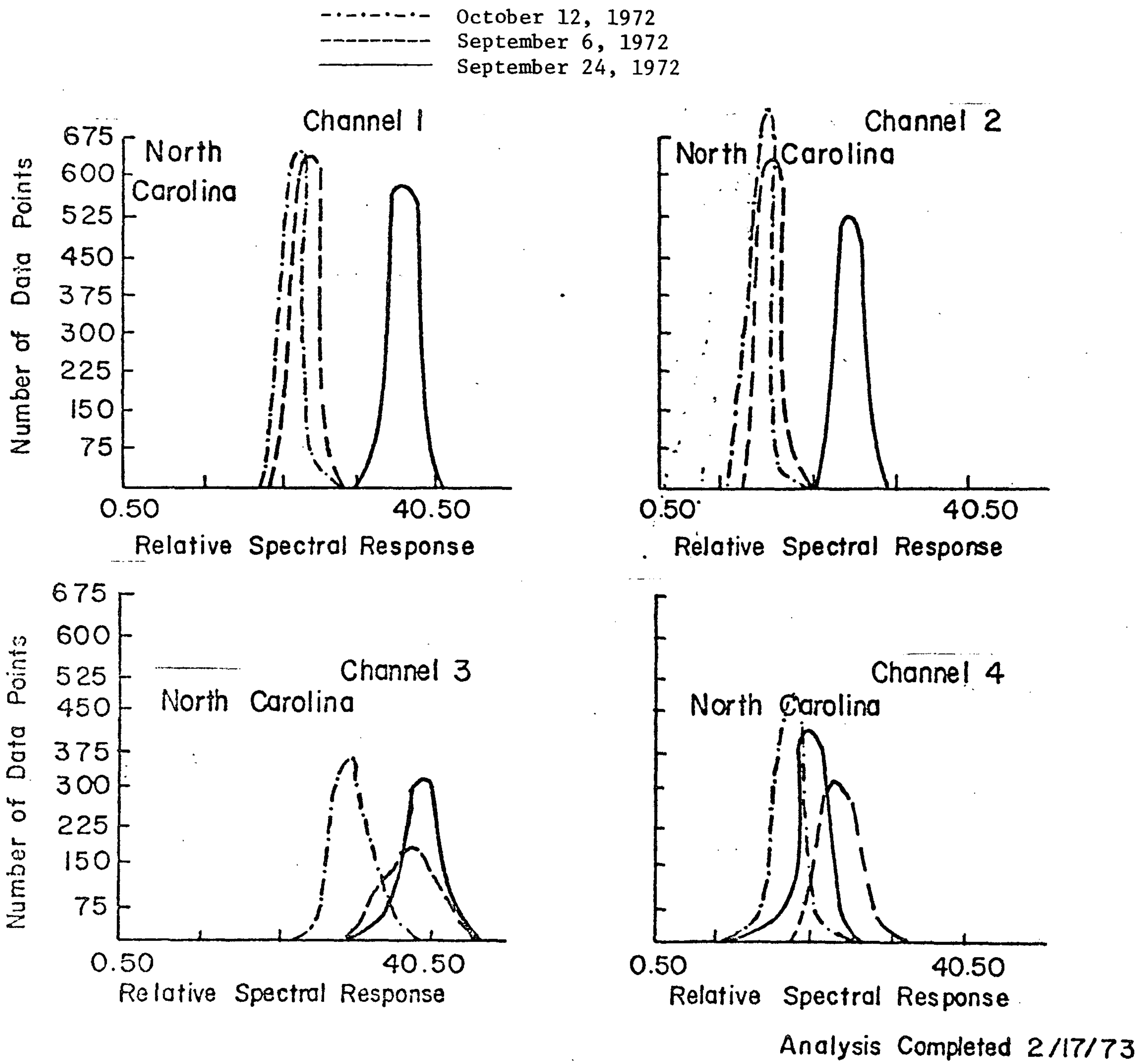

Figure 13. Time lapse analysis of North Carolina forested test sites.

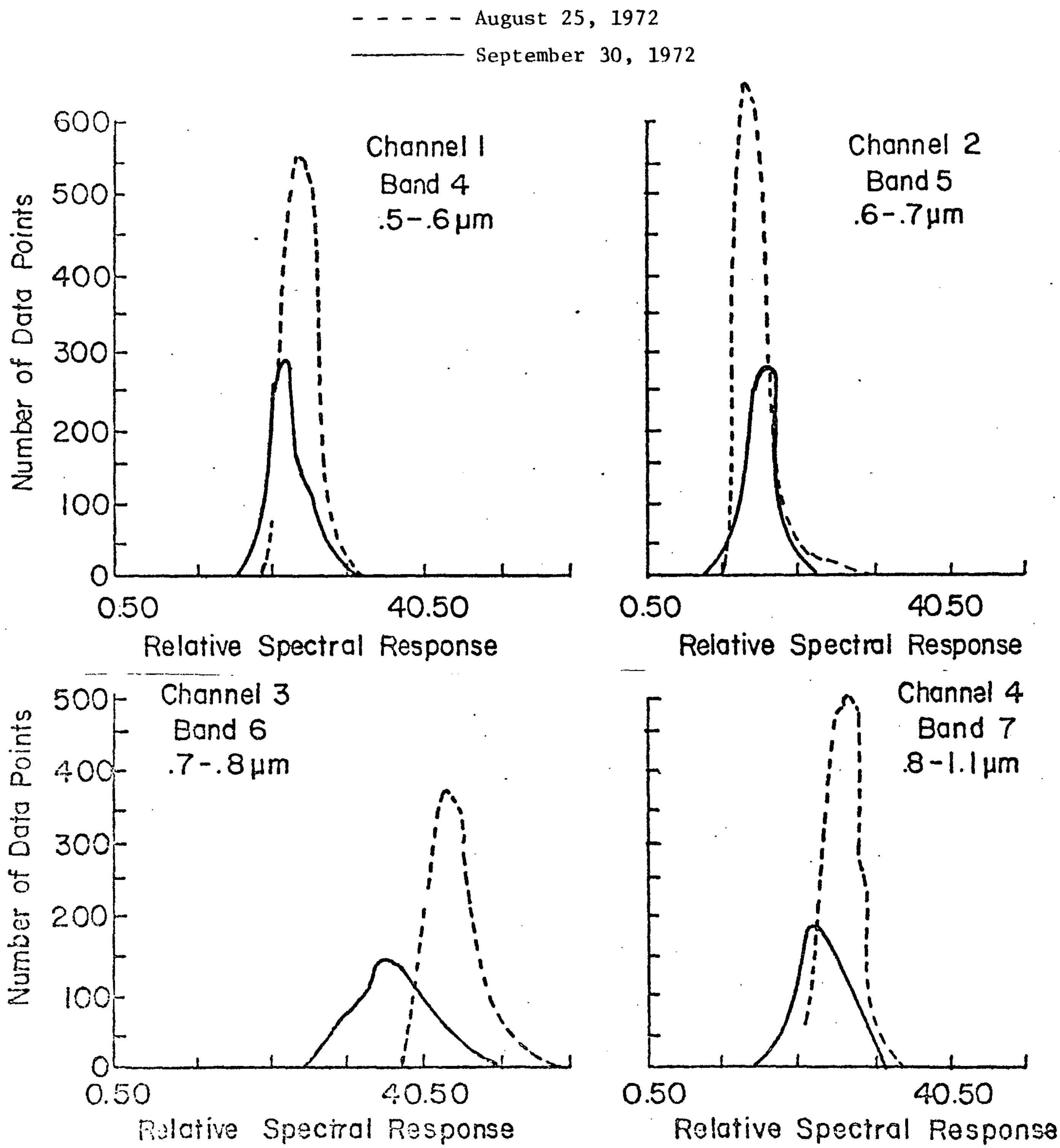

Figure 14. Time lapse analysis of Michigan forested test sites.

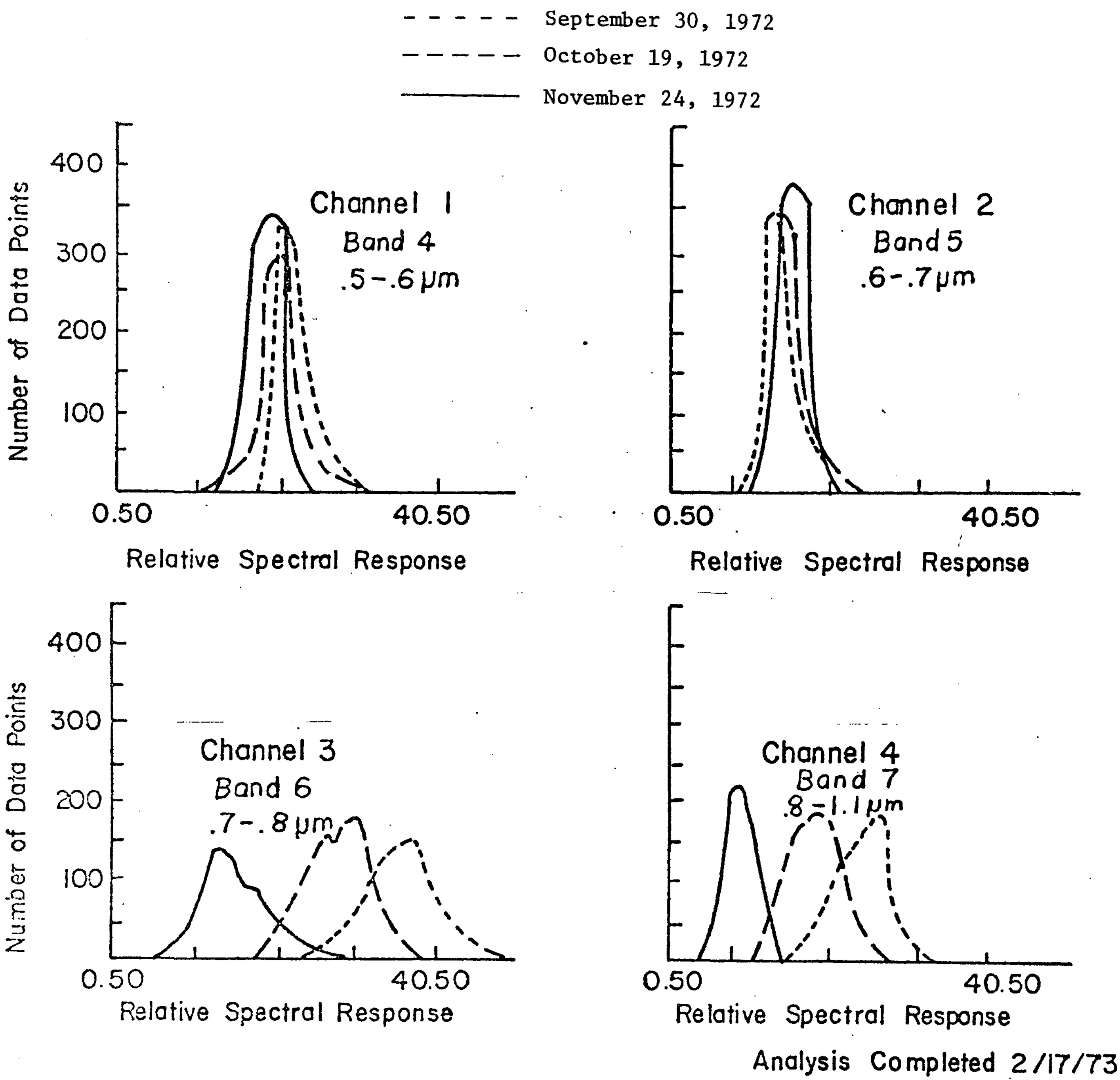

Figure 15. Time lapse analysis of Lafayette, Indiana forested test sites.

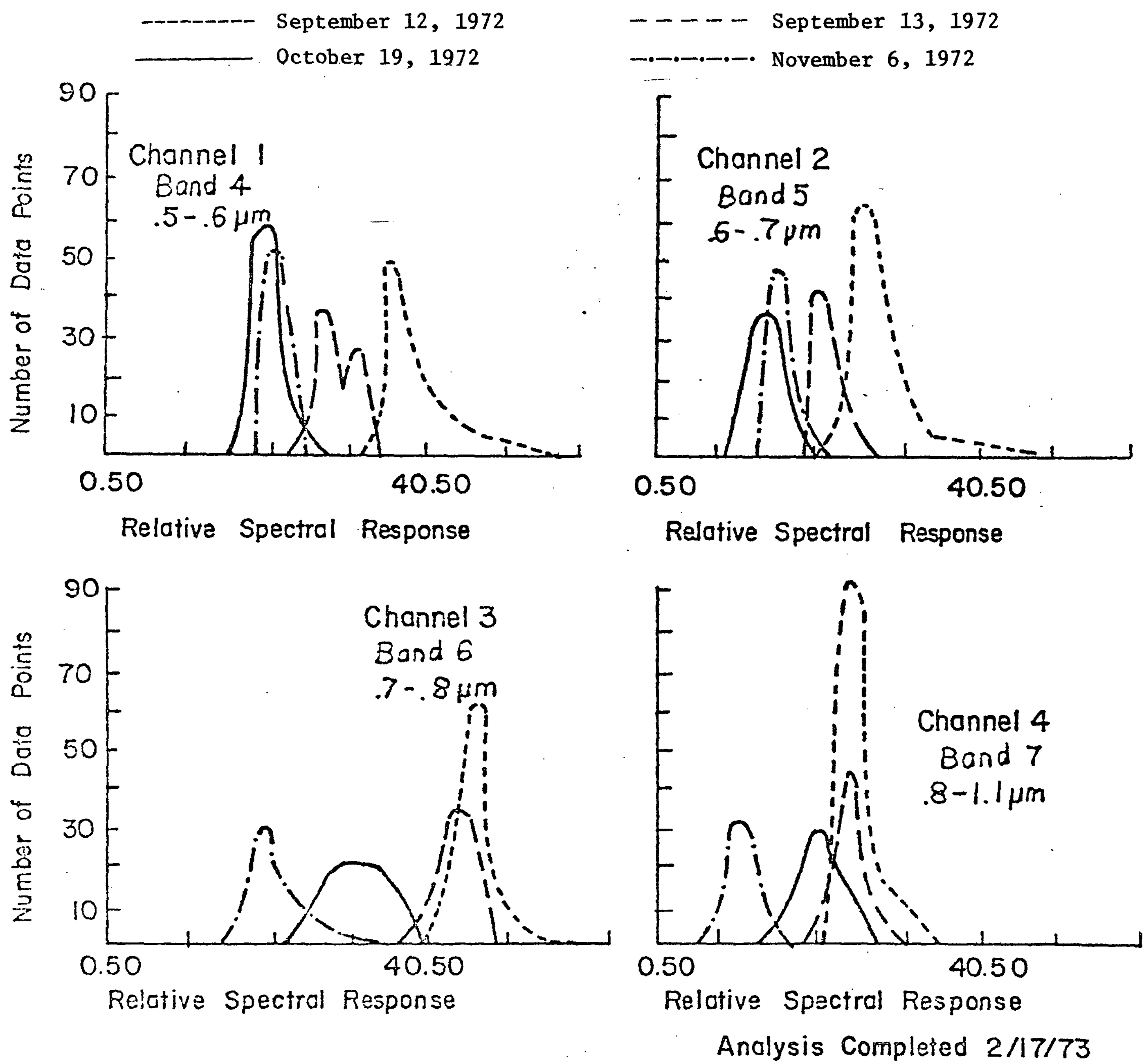

Figure 16. Time lapse analysis of Southern Indiana forested test sites.

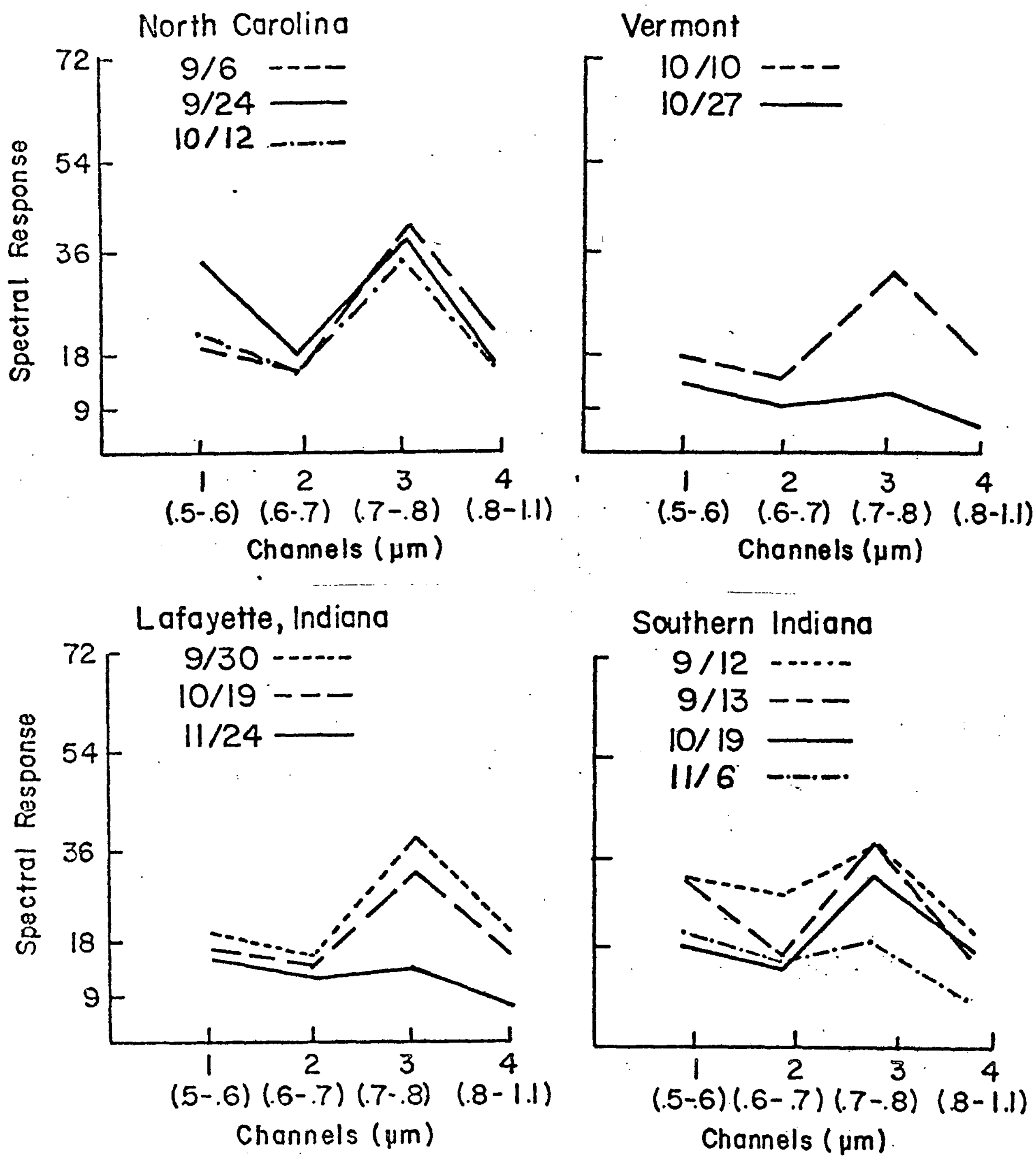

Figure 17. Coincident spectral plots comparison over time for each test site.

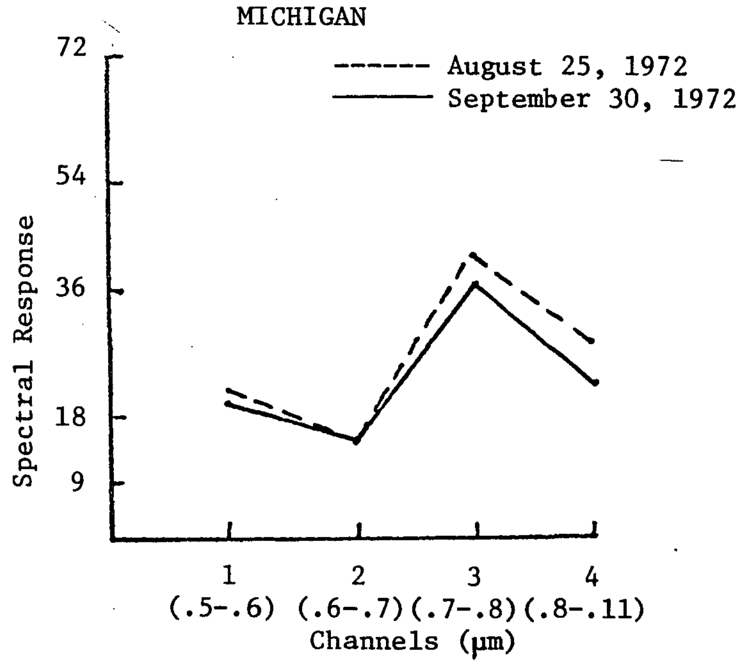

Figure 18. Coincident spectral plots comparison over time for each test site.

2.2.2 Photo Interpretation

United States Geological Survey maps (1:250,000), Agricultural Stabilization and Conservation Service (ASCS) maps (1:60,000 and 1:20,000) as well as ASCS aerial photographs were obtained for the areas of the ground observation sites. All the sites were located and recorded. This method insured the accurate delineation of site boundaries on 9x9 MSS positive tramsparencies. Establishing the locations of experimental sites on these tramsparencies is necessary before proceeding with photo-interpretation and the analysis of digital printouts.

Color composite transparencies have been prepared from 9x9 black and white MSS positive transparencies.

Photo-interpretation methods were used to construct time lapse sequences (Fig. 19-22). A similar type of sequence was collated using ground photography and forest cover measurements obtained from a Digicol Model 4010-30 density slicer. The Digicol has a planimeter attachment which is used to record the percent area of different density levels (example, sky versus foliage) within a photo. The changing percentages between sets of photography of the same scene over different dates reflect progressive foliage development or recession and represent a time lapse sequence of phenological change (8,9).

3.0 FUTURE WORK

During the spring and summer of 1973 work will be directed to the study of the second half of the objective, the Green Wave. Studies will also continue on the information obtained during the first six-month period.

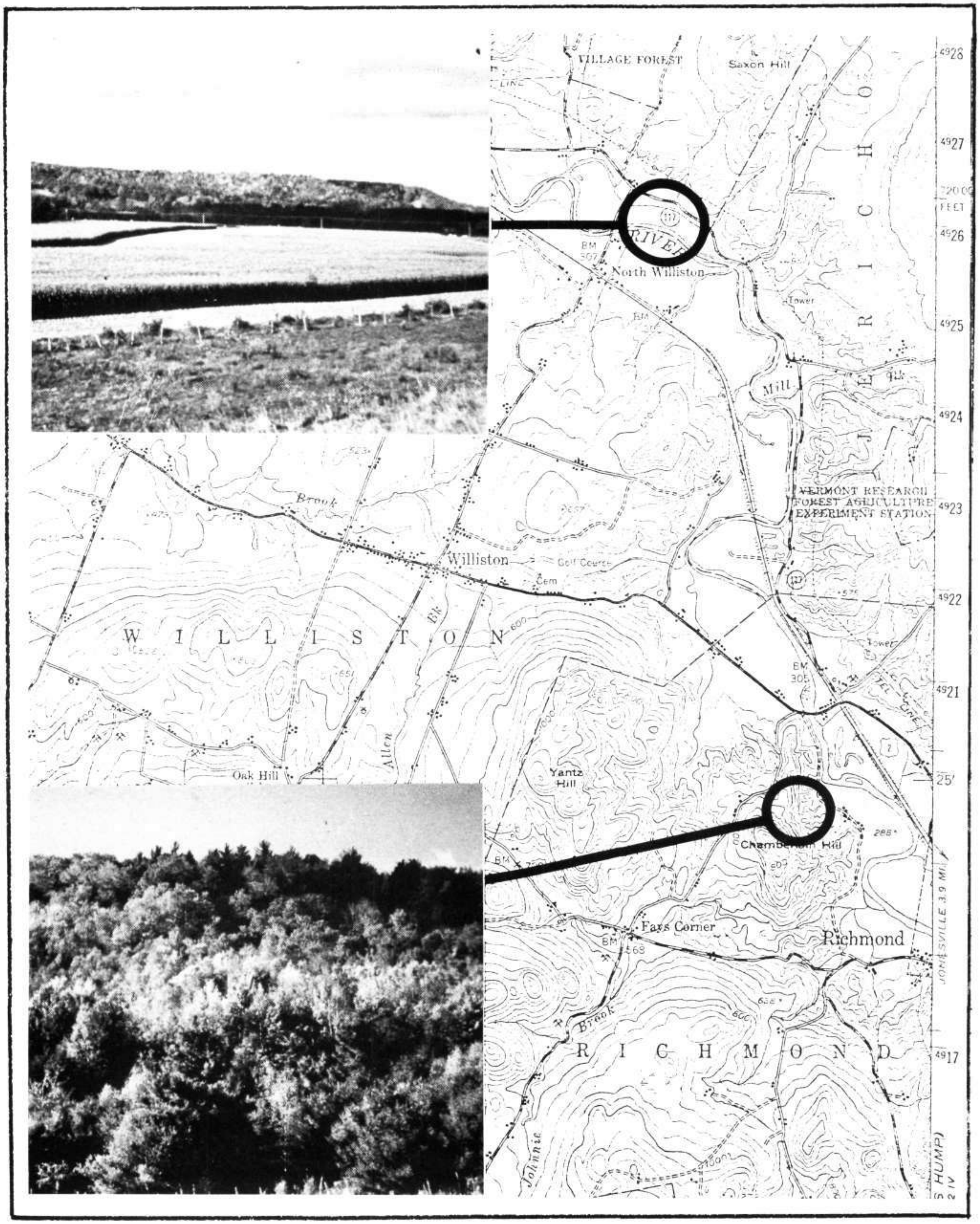

Figure 19. Northeast quarter of Burlington quadrangle showing cornfield and forest site (scale 1:62500).

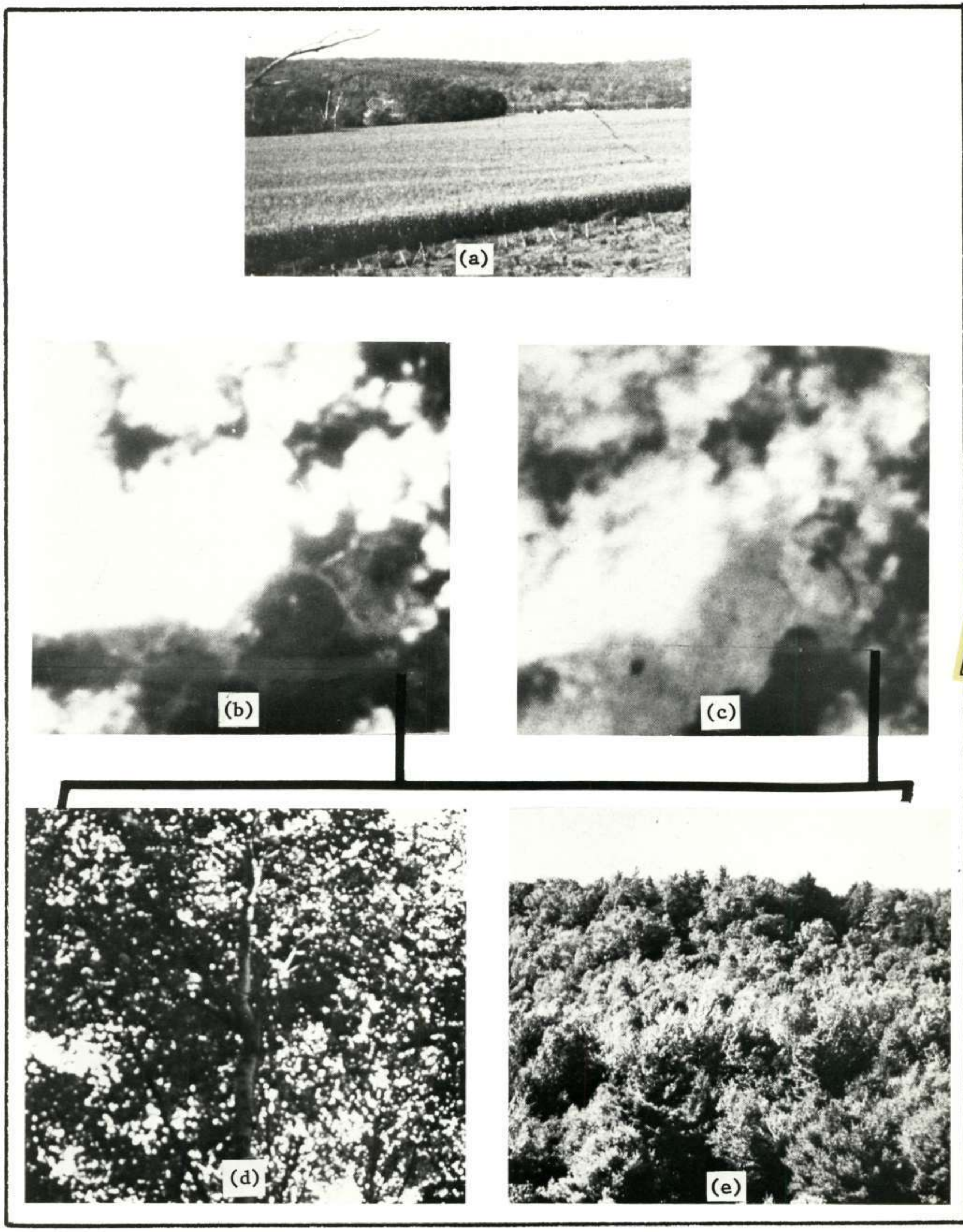

Figure 20. Ground observation photography and ERTS-1 imagery showing stages of vegetational development on 22 Sept 1972 at the Vermont Test Site: a) mature standing corn, b) MSS Band 5 (scale 1:125000), c) MSS Band 7 (scale 1:125000), d) forest canopy, and e) forest site.

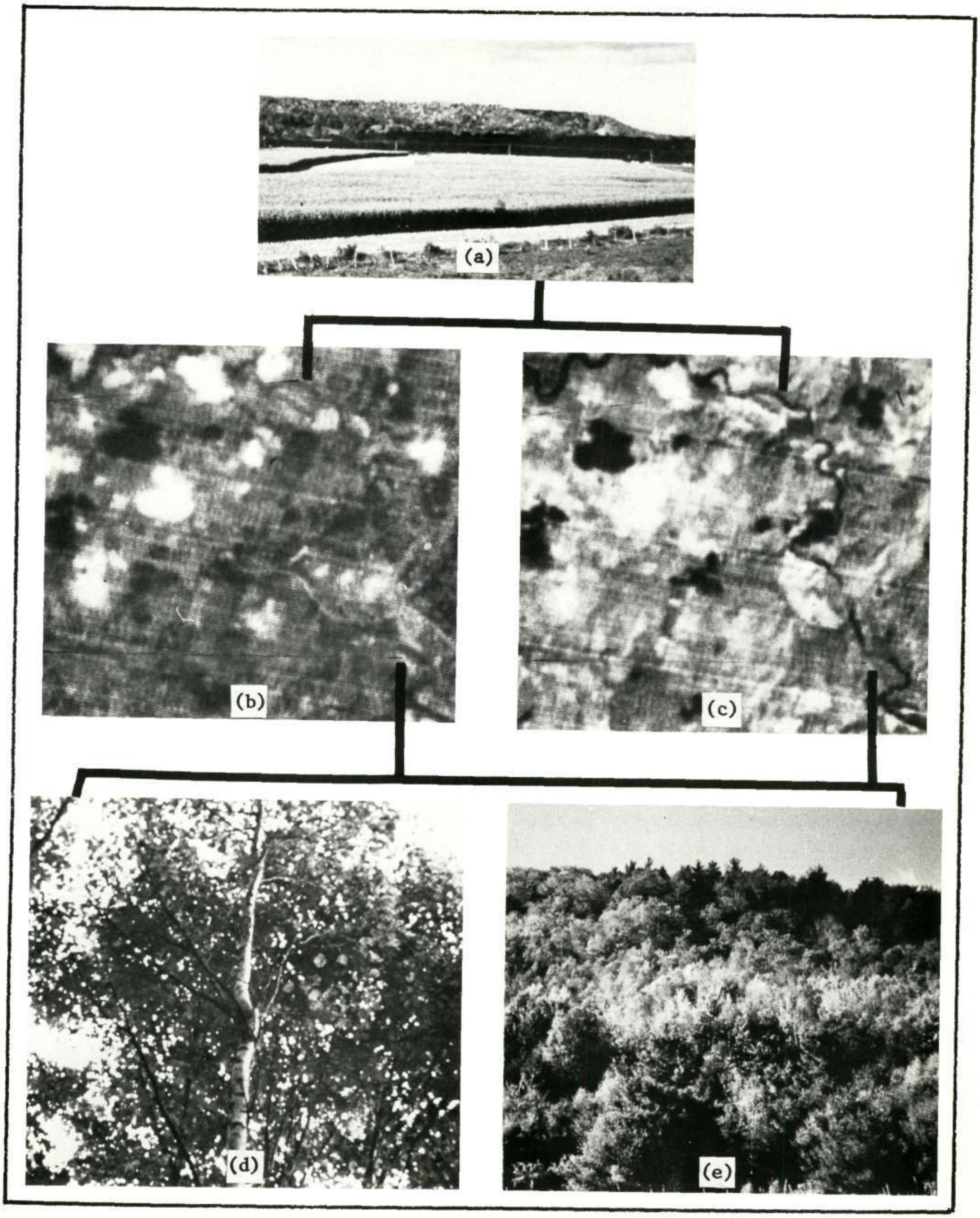

Figure 21. Ground observation photography and ERTS-1 imagery showing stages of vegetational development on 10 Oct 1972 at the Vermont Test Site: a) partially harvested corn, b) MSS Band 5 (scale 1: 125000), c) MSS Band 7 (scale 1:125000), d) forest canopy, and e) forest site.

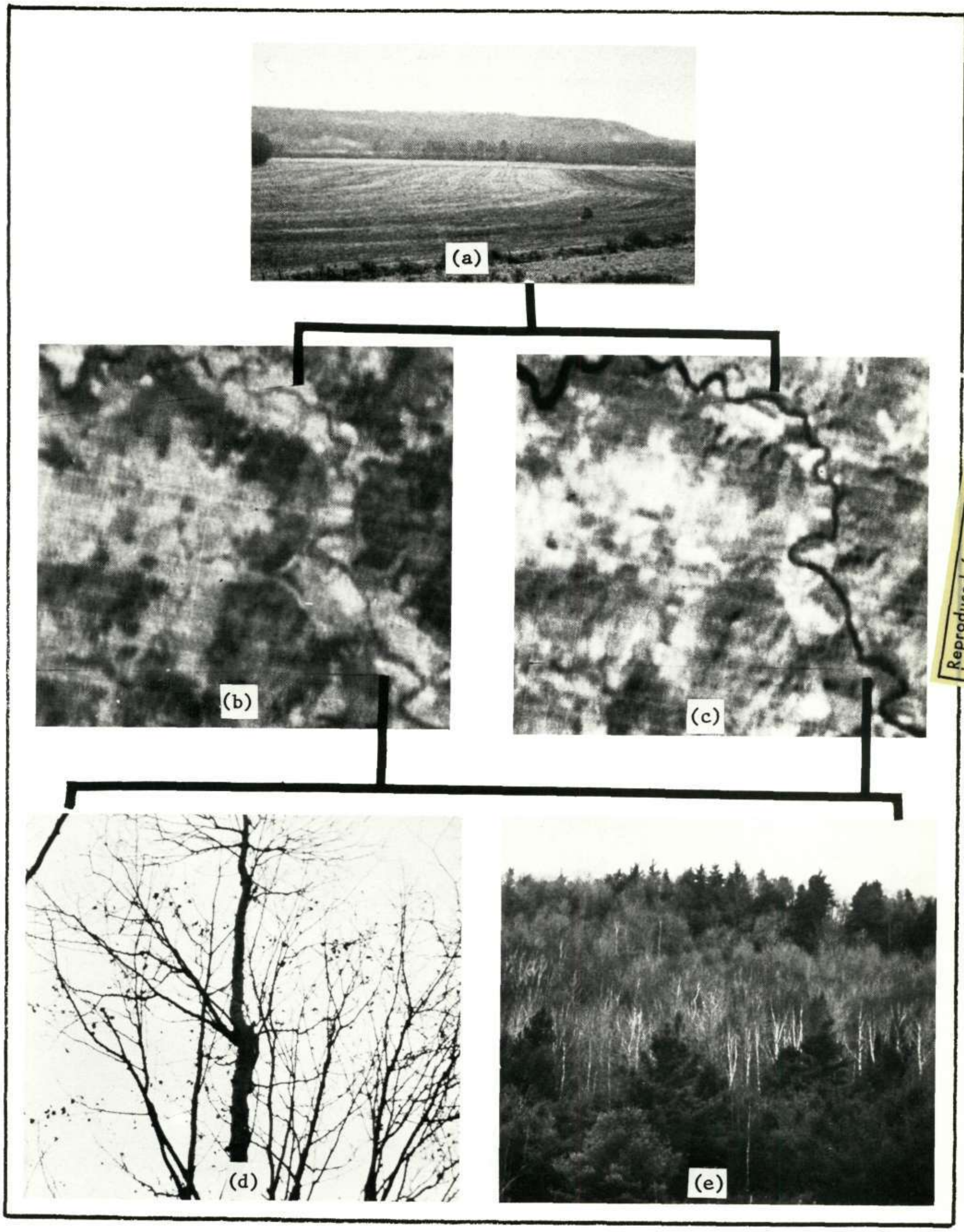

Figure 22. Ground observation photography (4 Nov 1972) and ERTS-1 imagery (27 Oct 1972) showing stage of vegetational development at the Vermont Test Site: a) corn stubble, b) MSS Band 5 (scale 1: 125000), c) MSS Band 7 (scale 1:125000), d) forest canopy, and e) forest site.

3.1 GROUND OBSERVATIONS

Preparations are being made for computer mapping of the Brown Wave in the fall of 1972 and for the Green Wave in the spring of 1973. Visual ground observations by hundreds of observers throughout the country will be the data input for these mapping analyses.

3.2 SOLAR THERMAL UNITS

Solar thermal unit accumulations during the 1973 growing season will be compared with phenological development and satellite information from selected locations throughout the world.

3.3 DATA PROCESSING

Upon receipt of the other fall season data tapes the study of the 1972 Brown Wave will continue. Also, there are dates for which even imagery has not been received. This situation has hampered progress, but it is hoped that analysis of the rest of the Brown Wave data may be made before receiving data for this spring's Green Wave.

Other aspects of analysis which are just now beginning to be included are: application of correction factors to the raw statistical data obtained so far, comparisons between test sites for similar seasonal periods (this will utilize data from sites where only one good passover date occurred), simulated infrared color photographs obtained from the digital display to enhance gross features from a test site region, and refined species identification for forested test sites. Since mostly forested areas have been dealt with so far, a simple printout using the visible band 5 of the MSS data was sufficient to uniquely identify the class. However, when analyzing various crops in the spring data, a more sophisticated classification will be necessary.

Since this experiment is essentially a temporal study, there are certain variable factors which to some degree effect the statistical results obtained thus far. The data will be corrected for the following variables: solar elevation, changes in gain setting (affecting bands 4 and 5 only), and atmospheric conditions.

On some reoccurring basis (as dictated by data availability, a phenological change, and other as yet undetermined variables) data cataloged for each test site will be collected, analyzed, summarized, and presented in a comprehensive computer printed report. This report will summarize the calculated data from throughout the transects and present this information graphically with both time and latitude on the abcissa. This information will be presented in a comprehensive analysis report which is produced at a seasonal rate.

Continuing data analyses will be performed to enhance investigator understanding of the phenological processes and their relationships to other regional variables, as well as the understanding of the actual ERTS measurement processes. By maintaining computer catalogs of the processed data, this information can be compared with other promising data sources, such as meteorological data measurements from Nimbus and other satellites. It is anticipated that these analyses will be for the most part, restricted to those of a statistical nature such as regression and correlation analyses. Such analyses will serve to indicate where the quantitative variability in the investigation might be significant and will tend to establish, at least qualitatively, confidence bounds on the investigation results. With the careful logging and storage of the ERTS data as described, these data will also be available for further studies not directly related to this project, which might be of concern to state and local agencies.

3.4 PHOTO INTERPRETATION

As more imagery is received, documentation of the Brown Wave will be completed. The advance of the Green Wave during the spring of 1973 will be studied using the methods perfected during the first six month period.

3.5 PHENOCLIMATIC MODELS

Phenoclimatic models will be developed and preliminary world maps drawn for the following events:

1. the green wave
2. begin bloom of lilac
3. yearly total evapotranspiration
4. number of alfalfa cuttings per year

4.0 CONCLUSIONS

Due to delays in reception of ERTS-1, data analysis proceeded at a faster rate for the two eastern-most corridors than for the two western corridors. However, the correctness of the data handling plan was proven. The computer programs developed have been tested and show that small fields, several hectares in area, can be identified. Recognition of some types of vegetation as well as some phenological changes were documented (10).

Preliminary analysis of digital data shows that a systematic decrease in reflectivity in the infrared channels occurred for the August to November period. This change reflects the progression of the Brown Wave with time at the different test sites.

The significance of the shift will be determined following an investigation of the magnitude to which the aforementioned corrective factors influence the data. It can already be seen that for dates where much haziness was present in the imagery (notably Southern Indiana 9/12), radical departures from the expected curves occurred.

From this year's ground observation photography it was shown that vegetation senescence does not progress evenly from north to south. Thus, the satellite's synoptic view is necessary to map intermediate changes between existing ground observation sites. Site elevation, soil or other natural factors can result in phenological events such as leaf fall occurring on the same date on areas hundreds of miles apart. A photo-interpretation study of imagery in bands 5 and 7 over two dates indicate that such events as crop harvest and leaf fall can be mapped for specific areas and possibly for entire regions.

Comparison imagery taken before and after leaf fall can be used to map softwood and hardwood areas. For example, a land use and forest classification study was made using the October 27 MSS-5 imagery of the area around the Richmond, Vermont test site. Only that area which could be compared with a USGS topographic sheet was mapped. The resulting data is shown below.

Forest	Area (Acres)	Percent of Total
Softwood	1883	34
Mixedwood	415	7
Hardwood	532	10
Other		
Fields, farms, urban	2483	45
Water	210	4
	5523 Acres	100 Percent

This finding was reinforced by the computor analysis of other ERTS-1 data. Species identification was performed for two Vermont forested test sites. In the analysis of the Vermont data, two distinct forest classes were identified which ground truth later verified to be a deciduous and a coniferous stand, respectively. Separation of the two types was made through statistical analysis of the two infrared scanner bands, 6 and 7. A study is also being made of several forested sites around Lafayette, for which precise tree mapping ia available, to see if different types of deciduous trees can be identified.

Such identification might be of aid to various land use planners and those interested in forested regions, such as lumber companies, recreational facilities or highway planners.

Results to date from the Phenology Satellite Experiment shows the feasibility of the development and refinement of phenoclimatic models.

Satellite data, such as that received from ERTS-1, will make world-wide phenological monitoring possible. This is necessary to develop universally applicable phenoclimatic models.

For countries with highly developed agriculture, such information would be useful in characterization of crop status, yield prediction, and management planning. Phenological data in less-developed countries could be useful for agricultural land use planning and for determining site suitability.

In the final analysis, the success of Earth Resources Technology Satellites will depend on the ultimate use of interpreted data. In the agricultural, forestry, and related segments of the economy these data will contribute to decision-making of economic significance in management, provide more accurate estimates of acreage and yield forecasts of many commodities. The means of disseminating the interpreted data to the user is available through Cooperative State Extension Service. Working with the Scientists from the State Agricultural Experiment Stations, extension specialists could be trained to incorporate satellite derived information into their state advisory programs.

5.0 RECOMMENDATIONS

Since atmospheric conditions can play such an important part in any time lapse analysis, it will be important to obtain radiation data. This data will make a more meaningful analysis of certain test sites.

Aircraft underflights would be of additional value where forest test sites are used, as such flights would yield a more accurate representation of the entire forest canopy.

Future work will proceed along the lines outlined and will build upon the techniques developed and methods used during the first six months of the study.

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